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IMPACT BEHAVIOUR OF BIO-INSPIRED SANDWICH BEAM WITH VARYING CORE GEOMETRIES

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Grade: ____________

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Final Year Project Report ☑

Masters ☐

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ABSTRACT

Impact resistance efficiencies of the bio-inspired sandwich beam (BHSB) with varying solid hot melt adhesive (HMA) hyoid core thicknesses and leg spans were examined under the impact energy of 7.28J at the mid-span of the sandwich beam. The sandwich beam models consist of dual-core comprising solid hot melt adhesive (HMA) and aluminum honeycomb cores sandwiched between the top and bottom carbon fiber reinforced plastic (CFRP) skins. The HMA core was designed with an arch shape. Considered HMA hyoid thicknesses include 3 mm, 4.574 mm, and 10 mm with various leg spans of 10 mm, 25 mm, and 35 mm. The finite element software, ABAQUS, was used to construct the BHSB models in examining the impact behaviors of these models. Assessed performances include displacement-time, velocity-time, acceleration-time, impact energy-time, and stress contour distribution. Then, the impact resistance efficiency index was used to determine the overall performance of all the BHSB models. In conclusion, the BHSB with HMA hyoid thickness of 4.574 mm and a hyoid leg span of 10 mm is the most superior in terms of impact resistance efficiency index among all the proposed sandwich beam models as it has the highest impact resistance efficiency index of 25.53.

ABSTRAK

Kecekapan ketahanan hentaman bagi "Bio-inspired sandwich beam" (BHSB) dengan ketebalan "Solid Hot Melt Adhesive (HMA) hyoid core" yang berbeza-beza dan jarak kaki yang berbeza-beza diperiksa di bawah tenaga hentaman dengan "7.28J" di tengah BHSB. BHSB mengandungi dua lapisan terdiri daripada "solid hot melt adhesive (HMA) core" dan "aluminium honeycomb core" yang dilekat di antara kulit atas dan bawah yang dibuat daripada "carbon fiber reinforced plastic" (CFRP). "HMA hyoid" direka bentuk dalam bentuk lengkungan. Dalam kajian ini, ketebalan "HMA hyoid" yang dipertimbangkan merangkumi 3 mm, 4,574 mm dan 10 mm dengan pelbagai jarak kaki iaitu 10 mm, 25 mm dan 35 mm. Perisian elemen aplikasi, ABAQUS digunakan untuk membina "BHSB" model untuk mengkaji tingkah laku impak bagi "BHSB" model. Prestasi yang dinilai merangkumi masa perpindahan, masa halaju, masa pecutan, masa tenaga impak, dan taburan kontur tekanan. Kemudian, indeks kecekapan rintangan hentaman digunakan untuk menentukan prestasi keseluruhan bagi semua "BHSB" model. Kesimpulannya, "BHSB" dengan 4.574 mm ketebalan "HMA hyoid" dan 10mm jarak kaki "HMA hyoid" adalah yang paling unggul dari segi indeks kecekapan ketahanan hentaman di antara semua "BHSB" yang dicadangkan kerana dia mempunyai indeks kecekapan ketahanan hentaman yang paling tinggi iaitu 25.53.

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θ	- Angle of curvature
L_{arc}	- Length of arc
l	- the span
t_f	- Face plate thickness
t_w	- Core plate thickness
L	- Sandwich plate length
B	- Sandwich plate width
H	- Sandwich plate height
h_c	- Height of core plate
s	- Spacing between two adjacent core plates
I_e	- Impact resistance efficiency index
t	- Thickness of sandwich beam

CHAPTER 1

INTRODUCTION

1.1 Research Background

Sandwich structure is defined as the composite structures with multilayer, developed for the expected lifetime loading conditions (Birman and Kardomateas, 2018). Sandwich structure is applied extensively in aerospace field, the beams and columns, refrigerated storage, automobile and shipbuilding industries (Davies, 2001). Sandwich structure is extremely lightweight type of construction with high stiffness, long lasting, high strength and good thermal and sound insulators. Those advantages encourage the wide uses of sandwich structures in the structural application (Zaid et al, 2016). Figure 1.1 shows the loadings carried by skin and core of sandwich structure (Campbell, 2010).

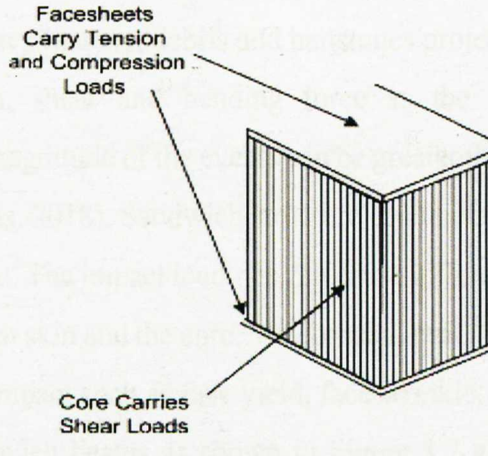

Figure 1.1. Loadings carried by face and core of sandwich structure (Campbell, 2010).

Sandwich structure consists of three parts which two relatively thin stiff and high strength skins are separated by a lightweight thick core which has enough stiffness in direction normal to the skins. Sandwich structure enables design of multi-functional structures which can be achieved by uniting different skins and materials of core (Davies, 2001). The materials of the sandwich structure are chosen based on the usage of the structure, loading, availability and cost (Birman and Kardomateas, 2018). The core can vary in thickness, density and solidity and it occupies small percentage of the sandwich weight. The sandwich structures' structural performance is influenced by the skin properties and the core properties, adhesive connection of the core and the skins and geometrical size of the components (Daniel and Abot, 2000).

The facings are made of steel, aluminium, wood, fibre-reinforced plastic, carbon, aramid and even concrete while the core is made of solid plastic material such as polyethylene, rigid foam material such as polyurethane, polystyrenem and phenolic foam, metal and non-metal honeycombs of metal and non-metal (Davies, 2001). Usually a sandwich structure has relatively thin skin sheets which is ranged from 0.25 to 3 mm while the densities of the core is around 16 to 480kg/m^3 (Campbell, 2010). In aerospace applications, the facings of the sandwich structure are typically made of synthetic granite and synthetic carbon while the facings of civil and marine structure are made of glass-epoxy. Aluminum or Nomex honeycomb is used as core for aerospace structures while the closed-cell or open-cell foam are the core used in civil engineering while the ship sandwich structures use balsa with different density as its core (Birman and Kardomateas, 2018).

Sandwich structure can be damaged internally and externally by the impact loads such as bird strike, drop of heavy matters, debris and hailstones projectiles regarding to reduction in tension, compression, shear and bending force as the impact loads will happen instantaneously and the magnitude of the events can be greater than that of its static condition (Birman and Kardomateas, 2018). Sandwich structure can undergo many different modes of failures in an impact event. The impact loadings can cause different modes of damage to skin, core and interface between skin and the core. McCormack et al. (2001) state that some failure during the low velocity impact such as face yield, face wrinkle, core failure and indentation will happen on the sandwich beams as shown in Figure 1.2 as cited in Sabah, Kueh and

Bunnori, 2019. Gibson and Ashby (1997) state that sandwich beam geometry and the materials strength for the core and skin will influence the type of failure as cited in Sabah, Kueh and Bunnori, 2019.

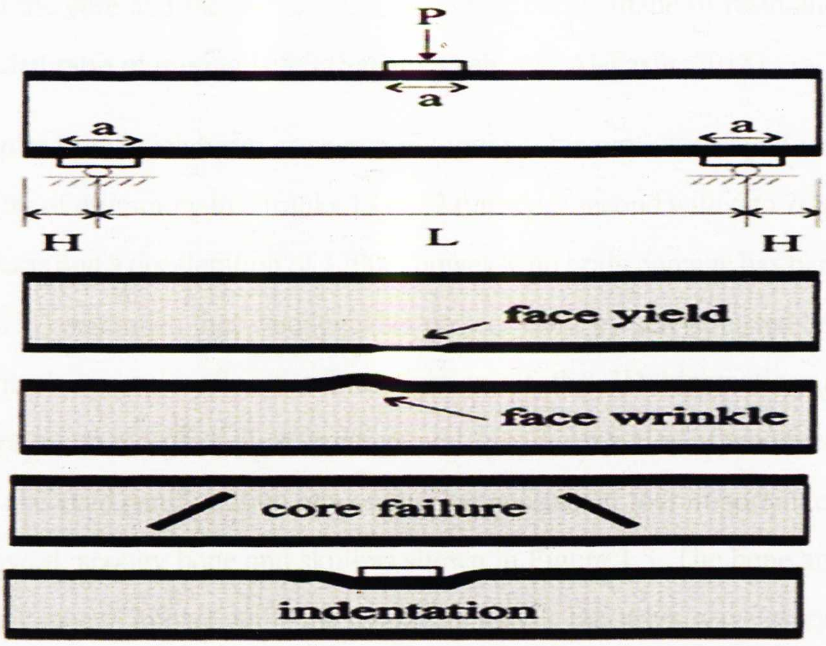

Figure 1.2. Failure modes of sandwich structure under low-velocity impact (Sabah, Kueh and Bunnori, 2019).

Low velocity impact does not able to perforate the structure as the damages are limited to the top skin, but the core will experience shear and slight damage in the bottom skin. The face yield happens when the skin experiences a complete fracture that is caused by the micro-tension. The face wrinkle defines the skin undergo some matrix cracking and fiber breakage because of micro-compression with no fracture (Sabah, Kueh and Bunnori, 2019).

Sandwich structure is good in resisting single impact but the resistance to repeated impact loadings is still not well maximized. Heimbs et al. (2010) as cited in Sabah, Kueh, and Al-Fasih, 2017 stated that sandwich structure with two cores has much higher stiffness and strength than other structures. The combination of two core enhances the resisting power of sandwich structures toward impact. Therefore, bio-inspired honeycomb sandwich beam (BHSB) is introduced. BHSB is made of four layers which the first and last layer was formed by CFRP made of three layers unidirectional T350/EP-1006 which is the first line defense that protects the sandwich structure from impact damage The second layer was the rubber core I with a thickness of 3 mm which spreads and absorbs the impact excitation. The rubber is used as the core materials as it plays the role to absorb the load in handling the incoming impact force. The third layer was made of aluminium honeycomb core (core II) with cell size of 8 mm, thickness of 20 mm which can suppress any further impact. The EP-1006 adhesive is used to bond the core and the skins. The EP-1006 adhesive made of resin and hardener. The recommended ratio of mixing is 5:3 (Sabah, Kueh, and Al-Fasih, 2018).

Bio-inspired sandwich beam as shown in Figure 1.3 is motivated by the woodpecker with its capability of drumming tree trunks 18 to 22 times per second with 6 to 7m/s repeating high speed impacts and a deceleration of 1200g, however no brain damage has been detected. Wang et al. (2011) examined that woodpeckers protect itself by self-adjusted behavior and special anatomical structure after the investigation of the 3D kinematics, mechanical properties macro/micro morphological structure and dynamic reaction of woodpecker's head quantitatively. The head configuration of woodpecker consists of four important components such as beak, hyoid, spongy bone and skull as shown in Figure 1.3. The bone and beak can increase the resistance to impact while the hyoid can reduce the stress wave essentially from beak to the skull. Besides that, the overall stresses in skull and brain were minimized which is safe. The beak, hyoid, spongy bone and skull of a woodpecker are representing CFRP, rubber core, aluminium honeycomb core and another CFRP respectively (Sabah, Kueh and Al-Fasih, 2018).

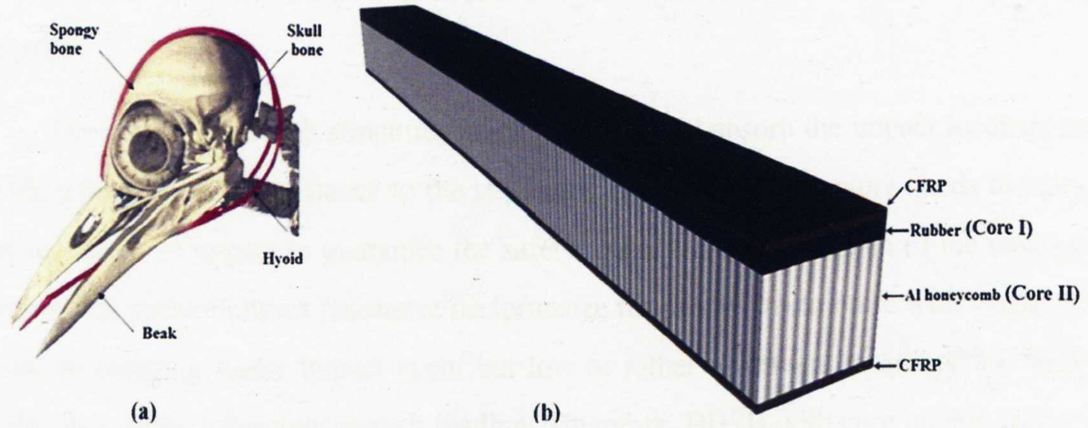

Figure 1.3. a) Head configuration of woodpecker and b) Bioinspired sandwich beam with honeycomb core (Sabah, Kueh and Al-Fasih, 2018)

The BHSB with two cores can enhance the resistance to impact but the capability of its impact resistance is still an unknown. Therefore, Sabah, Kueh, and Al-Fasih (2018) compared the effect of low-velocity impact toward conventional sandwich beam with honeycomb core (HSB) and bio-inspired sandwich beam with honeycomb core (BHSB). Sabah, Kueh, and Al-Fasih (2018) conducted investigation experimentally and numerically with a good result showing that BHSB is 5 times better than HSB as regarding to the overall impact resistance behavior. HSB is made of two carbon fibre reinforced plastic (CFRP) skin which is separated by aluminium honeycomb core. The unique properties of the cores made of honeycomb and solid viscoelastic materials can fulfill the design criteria.

1.2 Problem Statement

The previous studies on the influence of geometrical change of sandwich structure proved the impact efficiency of a sandwich structure is affected by the core and face thicknesses, curvature angle, spacing between core plate, core length, core cell wall thickness and immediate layer of the core. Sandwich structure is exposed to a succession of impacts during lifespan. Therefore, high resistance and high strength sandwich structure is needed. The problem is basically on how to create a lightweight sandwich structure with strong properties.

The core in sandwich structures helps to spread and absorb the impact loadings and provide a better impact resistance to the structure. The sandwich structure needs to have a good resistance to impact to guarantee the safety, quality and the lifespan of the structure. However, the current impact resistance performance for sandwich structure with single core is good in resisting single impact event but low or rather unknown capability for further functionality when subjecting to such loading. Therefore, BHSB with core in arch shape of 36° angle is proposed for this study as the arch shape can handle high loading as compared to flat shape and the arch shape reacts to the impact with a smaller peak displacement than flat shape.

Hence, this study is conducted to evaluate the effect of geometrical change such as core thickness and leg span of core I which is solid hot melt adhesive (HMA) on the impact behavior of the sandwich beam. The reason of studying the effect of core thickness is because no much studies evaluated the how the impact response of sandwich structure was influenced by core thickness under low velocity impact loadings. Through changing the core thickness, the ability to obtain interesting properties and desired performance is almost possible. Thicker core is better choice as it has higher impact resistance and absorbs higher energy. The effects of leg span on the efficiency of sandwich structure is studied as none of studies have been conducted on the effect of leg span and arch shape sandwich beam will offer a higher impact resistance structure.

1.3 Aims and Objectives

This study is conducted:

- To develop a composite sandwich beam finite element model under impact loading.
- To numerically examine the impact behavior of the sandwich beam due to varying core thickness and arch core leg span.
- To compute the impact efficiency of the sandwich beam due to varying core thickness and arch core leg span.

1.4 Scope of Study

The scopes of study are as shown below:

I. The sandwich beam is a C-clamp supported at two ends.

II. Only one impact energy of 7.28J is applied perpendicularly at the centre of the sandwich.

III. There are two core and one skin are used in the sandwich beam.